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Exploration of Pattern Recognition of Automobile Anti-Lock Braking System

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Data management systems have had a significant impact on society and the economy as they are an important means of storing information derived from big data by means of computer technology. Data management systems enable pattern recognition, which plays a significant role in information recognition and gradually extends to other areas. Due to the gradual popularization of automobiles, the requirements for safe automobile braking performance are increasing. In this regard, an ABS (Anti-lock Braking System) can adequately meet the current requirements for automobile braking performance. At present, the research on ABSs focuses mainly on its control strategy. In actual production, many ABSs use logic threshold control. However, the pattern recognition of ABS is rare. In order to promote the application of ABS, this paper proposes the idea of pattern recognition through theoretical analysis. By means of the pattern recognition of the initial speed, the overall situation of the road surface and the braking force when braking, the ABS system can effectively improve the driving safety of the automobile. The braking distance of the car with ABS system was reduced by 2 meters on the road with a high coefficient of adhesion, and 7 meters on the road with low coefficient of adhesion compared to the car without the system. This would help improve the safety of braking when the car is in emergency braking, and provide more driving security for the driver. Pattern recognition can also provide a more theoretical basis for the extensive use of ABS in cars. At the same time, the innovative application of pattern recognition can also enrich the information storage of the data management system and further its development.

Keywords: Anti-lock braking system (ABS); pattern recognition; PID control algorithm; automobile system

1. INTRODUCTION

Due to the gradual maturity of data management systems, they now play an important role in everyday life, which also provides more opportunities for the development of pattern recognition, and increases its areas of application. However, in the automotive field, the pattern recognition of the automotive ABS is rare. The ABS system is an important component that can improve the braking performance of the vehicle. It can reduce the braking distance of the vehicle by making the maximum use of the adhesion between the tire and the road surface, thus reducing the danger of the vehicle [1]. The theoretical basis of the ABS system dates back to the 1950s and 1960s, but its development has not been smooth. However, since the 1980s, with the rapid development of electric power technology, the reliability of the ABS system has been greatly improved. However, with continuous acceleration, problems such as tire jamming and dragging occur during braking. In order to make the application of ABS system in vehicles more suitable for current automotive developments, the research on this system focuses on improving the braking force and ensuring safe driving. In order to ensure the personal safety of drivers and passengers during the operation of vehicles, many scholars have conducted in-depth research to improve the ABS system. Through the anti-lock brake control system, a more perfect and effective solution to this problem has been obtained. It can be said that the appearance of ABS has greatly helped to improve

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the performance of vehicles. Through the pattern recognition of the ABS, it is anticipated that this paper will promote the application of the ABS in automobiles and improve driving safety. At the same time, it can broaden the application scope of ABS and enrich the theoretical application of pattern recognition [2].

Many researchers have approached the ABS from the optimization perspective, and indicated that their models perform better than the traditional ABS. Dankan [3] studied the modeling and performance evaluation of the ABS. He proposed the idea of an ABS based on a sliding mode controller, and compared the performance evolution of the proposed controller in terms of brake pressure modulation, vehicle speed, wheel slip and stopping distance. The results showed that the model purchased by the idea had better performance in all respects. Zhang [4] studied a new type of permanent magnet synchronous motor control for anti-lock braking in consideration of the transmission characteristics of electric vehicles. Considering the influence of transmission on the high dynamic braking process of pure electric vehicles, he proposed a new control method of permanent magnet synchronous motor, and built a model to compare the comfort, stability and mobility of electric vehicles' anti-lock braking system. The results showed that the performance of the new method was better. Wiseman [5] studied the efficient embedded computing components of the ABS. He proposed an idea of using efficient embedded computing components to build and optimize the ABS, and compared the improved system performance to show that the performance of this method was better [5]. Algadah and Alaboudi [6] studied the modeling of ABS components, and modeled and simulated the system behavior using simulation software. The results showed that the performance was better after modeling, which would help to visualize the system behavior. Although these studies on the optimization of ABS contributed to the theory and practical application of the system, they also had several shortcomings.

However, some scholars have discussed ABS from the perspective of automobile pattern recognition and put forward their views. Ouyang et al. [7] attempted to improve vehicle steering pattern recognition by using selected sensor data. They proposed a new method to reduce energy consumption and computational complexity, which improved the vehicle from three aspects and improved the recognition accuracy of vehicle steering mode. Boonsim and Prakoonwit [8] studied automobile manufacturing and pattern recognition under limited lighting at night. They found that the existing automobile manufacturing and model recognition method can be used only in the daytime, while many vehicle features cannot be detected in the limited lighting conditions at night. They proposed to use the available rearview function to identify vehicles at night. The experiments showed that this method can improve the recognition accuracy. These scholars have conducted various researches on vehicle patterns, and they have improved the accuracy of pattern recognition, which is valuable for further research on vehicle pattern recognition. However, because the research fields of scholars are different, and they conduct pattern recognition research on specific aspects of the vehicle or specific situations, this makes their findings not applicable to the pattern recognition of the vehicle ABS in this specific situation. Very little research has been conducted in pattern recognition of ABSs, indicating the need for more exploration of this issue in future.

The research on the pattern recognition of the ABS under multimedia modeling indicates that the ABS can be used in the automotive field. It can improve the performance and efficiency of automobile braking, and has a great deal of practical value and promotion significance.

2. THEORETICAL EVALUATION OF AUTOMOBILE ABS AND PATTERN RECOGNITION

2.1 Overview of Automobile ABS

At present, most ABSs adopt a closed loop brake, which generally consists of certain electronic control modules, hydraulic pressure, wheel speed sensors, etc., enabling the safety of vehicles to be monitored during operation. The installation of an ABS can monitor the driving condition of the vehicle to a certain extent, and can adjust the braking torque and control the slip rate accordingly so as to effectively prevent the locking of the vehicle and improve vehicle safety during driving [9]. Therefore, the installation of ABS on vehicles can improve both the control of vehicles and vehicle driving safety, and can help to further develop and promote the automotive industry [10].

2.1.1 Automotive ABS Components

The ABS comprises three main parts: wheel speed sensor, brake pressure regulator and electronic controller. These components are shown in Figure 1.

The wheel speed sensor is used to measure the speed of the automobile tire and send the speed signal to the corresponding electronic controller. Wheel speed sensors are either electromagnetic type or Hall type. The electromagnetic sensor has two main components: the sensing component and the ring gear. The electromagnetic wheel speed sensor has the advantages of simple structure and low cost. Therefore, it is widely used in automobiles [11]. However, it also has some problems. The Hall type wheel speed sensor consists of a sensing head and a ring gear. The sensing head has permanent magnets, Hall devices and related circuits. The output of Hall type wheel speed sensor is independent of the pulse signal of gear speed. When the vehicle power supply and voltage are 12 V, the output voltage of the engine remains between 11.5–12 V, and even if the speed drops below 0, there is no change. In addition, the frequency response of the Hall type wheel speed sensor is fast, reaching up to 20 frequencies. In an automobile ABS, this is equivalent to the system signal that can be detected when the wheel speed is 1000 km/h. The Hall sensor has strong anti-electromagnetic interference (EMI) performance. The brake force pressure regulator receives commands from the electronic controller unit (ECU) and connects the brake force pressure regulator and the brake master cylinder by means of the solenoid valve. The voltage of the electromagnetic switch is adjusted in order to

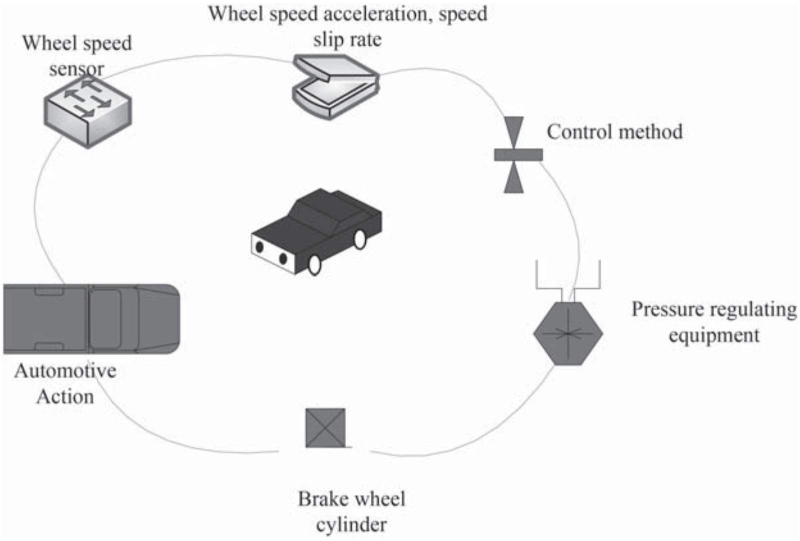

Figure 1 Components of automobile ABS.

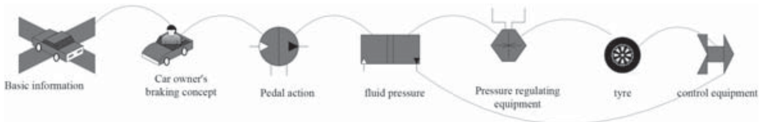

Figure 2 Schematic diagram of working principle of automobile ABS.

change the working mode of vehicle braking, which depends mainly on the reduction of pressure in the master cylinder [12]. The role of the anti-lock electronic control part of the car is to accept information from various sensors inside the car, and perform operations such as detection, comparison, decomposition, amplification and judgment. The maximum longitudinal slip value and the limit value of the tire in the braking movement of the vehicle are calculated so as to determine whether the vehicle has a problem such as steering failure. After that, the controller sends out the regulation command, and the control pressure is regulated by the brake hydraulic regulating valve to achieve braking. However, it is difficult to monitor the vehicle and brake when the vehicle does not have an ABS and needs to brake suddenly [13].

2.1.2 Working Principle of Automobile ABS

When braking, the vehicle “locks” and slides, which reduces the adhesion coefficient between the tire and the road, while the lateral adhesion coefficient is basically non-existent. These may cause accidents. In order to improve the adhesion between wheels and road surface and obtain the best braking effect, modern vehicles generally use electronic anti-lock braking devices [14]. As a passive protection measure, the ABS of vehicles has been widely used in the electronic brake pressure management system of vehicles. The system can automatically adjust the braking force during the whole braking stroke of the vehicle, so as to ensure the good driving safety of the vehicle during operation. This effectively prevents various dangerous phenomena such as vehicle steering failure and tail shaft side slip, thus reducing automobile accidents. When the device is operated, the braking force of the brake can reduce the speed of the car’s tires, and use the ground’s braking force to reduce the speed of the car. Hence, it can be seen that the adhesion of the road is closely related to the motion state of the wheels relative to the ground. The working principle is shown in Figure 2.

The basic working mechanism of the vehicle ABS system is discussed above. In a word, the ABS system maintains the slip rate within a certain expected range by adjusting the braking force of the electronic brake to maximize the braking torque. The electronic ABS of an automobile consists mainly of electronic components, including wheel speed sensor, deceleration sensor, brake force regulator, etc. This control system is designed to prevent the vehicle from locking. The wheel speed sensor is used to detect the vehicle speed, and the detected speed information is transmitted to the electronic controller. During the braking process, the speed of the car is compared with the deceleration information stored in advance in the electronic controller. The change of ABS braking force is shown in Figure 3.

2.1.3 Control Strategy of Automobile ABS

The key to understanding ABS is to analyze its control strategy. In view of the nonlinear characteristics of a vehicle anti-lock system, the development of a fast, efficient and optimal control strategy has become an important issue and a focus of research [15]. In recent years, many scholars have conducted numerous theoretical discussions on the control strategy of ABS.

In the vehicle anti-lock control, an angle deceleration valve can be set to a certain threshold. When the angle deceleration is greater than this threshold, the ECU sends a control command to reduce the braking power, and then the wheel speed increases. Hence, the ECU takes the selected

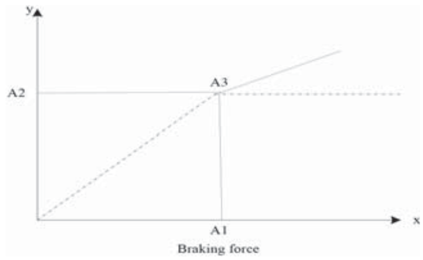

Figure 3 Change in ABS braking force.

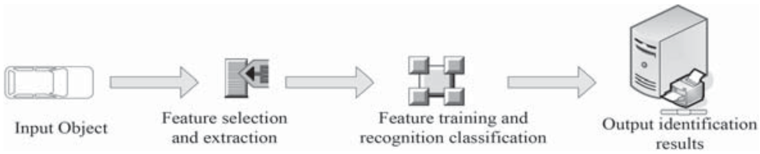

Figure 4 Main steps of pattern recognition.

angular acceleration as the control object. When the angular acceleration reaches this critical point, the ECU generates a control signal to increase the system brake pressure and reduce the wheel speed. The ECU can set appropriate angular acceleration and angular deceleration thresholds to achieve multiple adjustments of the ABS system, which makes it easier to work. Also, its structure is relatively simple. At the same time, if the angular acceleration and deceleration thresholds are set properly, better control effect can be achieved, which can be selected according to different needs. Of course, logic threshold control also has some defects. For example, the control logic is complex and unstable, and many control parameters are obtained by experiments, so there is a lack of sufficient practical demonstration to evaluate the overall stability.

Another modern control mode advocated in the state space theory, namely the optimal control strategy, can analyze the anti-lock and braking system of the vehicle within a limited time by using the mathematical model of the vehicle ground control system and relying on the state space theory. The optimal control method is different from the threshold setting control method. It is a control system method based on simulation analysis. Its basic logic is to set the optimal ABS suppression object according to the performance parameters of the anti-lock braking control system and the optimal control criteria [16]. The biggest advantage of PID (proportional, integral, differential) control is that it does not need to know the mathematical model of the controlled object, and it can be adjusted according to the real-time situation in actual work, so it can solve the modeling problem of ABS well. When the road adhesion coefficient of the PID controller is fixed, its characteristics give the system great practical value. However, in practical application, it is difficult to determine the standard tire model. By establishing a certain tire model, ideal slip rate can be obtained under different conditions, but this method is not practical in practical application. This study designed the single wheel tire of the vehicle, but cannot make an automatic judgment about the road condition. The PID control algorithm is used to control the slip rate of the vehicle, and it is applied to the automobile ABS system.

Fuzzy control is based on experience, not on a specific mathematical model. This method has simple logic structure and good stability. It is especially suitable for nonlinear, time varying and backward braking systems. In addition, there are also control strategies controlled by the sliding module structure [17].

2.2 Overview of Pattern Recognition

Pattern recognition is the process of processing and analyzing information in different forms (numbers and texts) about various things or phenomena, and describing, distinguishing, classifying and explaining them. Pattern recognition is widely used in many fields, while in the automotive field, it is mostly used to detect traces of automobile paint and defects in wheel hub casting [18, 19]. Pattern recognition comprises: feature extraction, feature selection, learning and training, and classification recognition. The main steps of pattern recognition are shown in Figure 4.

Feature extraction is a special method used to measure the characteristics of the identified object and digitize it, so that data input can be obtained. It is usually pretreated first, and then feature extraction is performed. After feature extraction, the target has a variety of features, which include not only the main characteristics of the measured object, but also the characteristics of interferences such as background and environment. The basic idea of feature selection is to choose only those features that are relevant to the prediction model being developed, as far as possible without affecting classification, which brings technical requirements for feature selection. Pattern recognition through feature selection can effectively save hardware overhead and speed up recognition. The goal of learning and training is to obtain classification and recognition rules, and use these rules for actual testing to achieve pattern recognition of unknown objects.

Pattern recognition technology is usually used for the prediction of a large number of known data and unknown data. Two kinds of problems are faced by pattern recognition and machine learning technology: unsupervised learning and supervised learning. Unsupervised learning is an artificial intelligence algorithm that classifies existing data in order to obtain the internal correlation information of general data. Unlike supervised learning, unsupervised learning cannot judge whether or not its training effect is correct in the learning process.

Supervised learning is used to establish the optimal model according to the given evaluation criteria, and determine the unknown data according to the obtained model. In this model, training data includes input and output. When the output of the model is continuous, this is known as regression; when the output of the model is a category label, this is called classification.

2.3 Algorithm of Pattern Recognition of Automobile ABS

The reason for pattern recognition of an ABS is to judge the performance of the system. The PID control algorithm can solve the modeling problem of an ABS system in pattern recognition, so it is also a key factor affecting the practical application of the system. This section introduces the PID control algorithm based on pattern recognition. PID control is divided into P (proportional) control, I (integral) control and D (differential) control.

The P control transfer function is:

$$F_a(z) = \frac{V_m(z)}{V_n(z)} = \frac{T_2}{T_1} \equiv H_q \tag{1}$$

where H_q represents the scale coefficient.

The I control transfer function is:

$$F_a(z) = \frac{V_m(z)}{V_n(z)} = \frac{1}{TAZ} \equiv \frac{1}{RZ} \tag{2}$$

The I control system can greatly improve the multiple anti-interference of the whole system. Therefore, the non-closed loop filling can be increased to reduce the difference in the non-dynamic state. However, if there is only I control, there may be phase angle lag, and the phase angle amplitude of the integral link decreases, which makes it usually unable to be used alone.

The D control transfer function is:

$$F_a(z) = \frac{V_m(z)}{V_n(z)} = TAZ \equiv RZ \tag{3}$$

D control can increase the shutdown times and phase angle amplitude of the system, and reduce the excessive part and adjustment time, thus improving the efficiency and stability of D control. If it is just a D control, the system changes more at higher frequencies, so the D control is not used alone.

The relationship between proportional and differential controllers is:

$$\omega(r) = H_q x(r) + H_B \frac{bx(r)}{br} \tag{4}$$

then the corresponding transfer function is:

$$F(z) = \frac{V(z)}{X(z)} = H_q + H_B z = H_q(1 + \frac{z}{y_b}) \tag{5}$$

$$y_b = \frac{H_q}{H_B} \tag{6}$$

The characteristics of proportion and difference can increase the system frequency width and shorten the adjustment time. It can enhance the anti-interference property of the PD control system and improve the stability of PD control. It can also increase the high-frequency interference in the system, which is conducive to the pattern recognition of the system.

The relationship between proportional and integral controllers is:

$$\omega(r) = H_q x(r) + H_M \int_0^1 x(r) br \tag{7}$$

then the corresponding transfer function is:

$$F(z) = \frac{V(z)}{X(z)} = H_q + \frac{H_M}{Z} = \frac{H_M \left(1 + \frac{Z}{Y_M}\right)}{Z} \tag{8}$$

$$Y_M = \frac{H_M}{H_q} \tag{9}$$

Proportional and integral control is the development of PI control type, which improves the non-static difference of PI control. It improves the anti-interference ability of PI to withstand multiple interferences. At the same time, the frequency width decreases and the adjustment time increases, which improves the recognition efficiency of the system.

The PID control algorithm mentioned in this paper is an effective optimization algorithm. It is a way to determine the corresponding error between the manually-set value and the actual input of the system, which can identify the overall performance of the ABS.

$$x(r) = t(r) - g(r) \tag{10}$$

The law of PID control is:

$$\omega(r) = H_q \cdot x(r) + \frac{1}{R} \int_0^1 x(r) b\sigma + R_b \frac{bx(r)}{br} \tag{11}$$

then the corresponding transfer function is:

$$F(Z) = \frac{V(Z)}{X(Z)} = H_q + \frac{H_M}{Z} + H_B Z \tag{12}$$

where $\frac{1}{R}$ is the integral coefficient and R_b is the differential coefficient.

The PID control algorithm based on pattern recognition is analyzed. The PID control algorithm is adjusted and optimized through proportional, integral and differential coefficients, which makes the PID controller better able to identify the patterns and work. The controller is installed in the automobile ABS system. Its purpose is to take the expected slip rate of the vehicle and the difference between the expected slip rate and the standard slip rate as the control target. By controlling the braking force output of the brake, it can ensure that the vehicle is within the predetermined slip rate range, so as to achieve better control and identification of the ABS system.

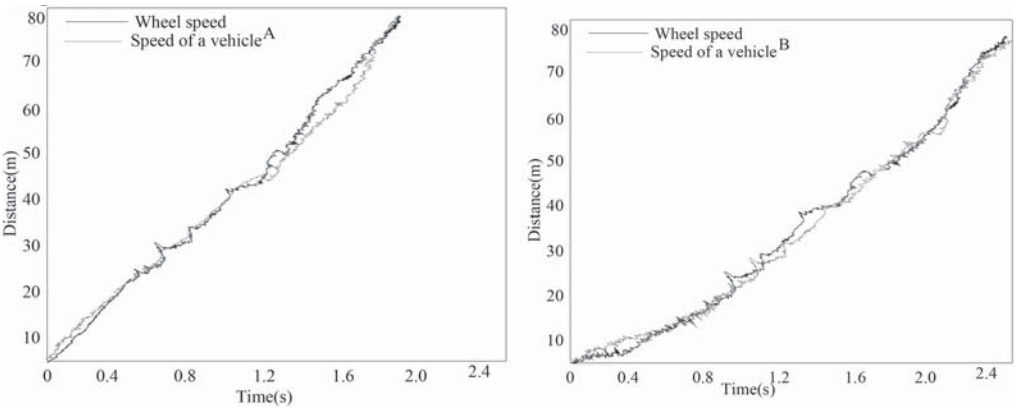

Figure 5 Comparison of wheel speed and vehicle speed pattern recognition results.

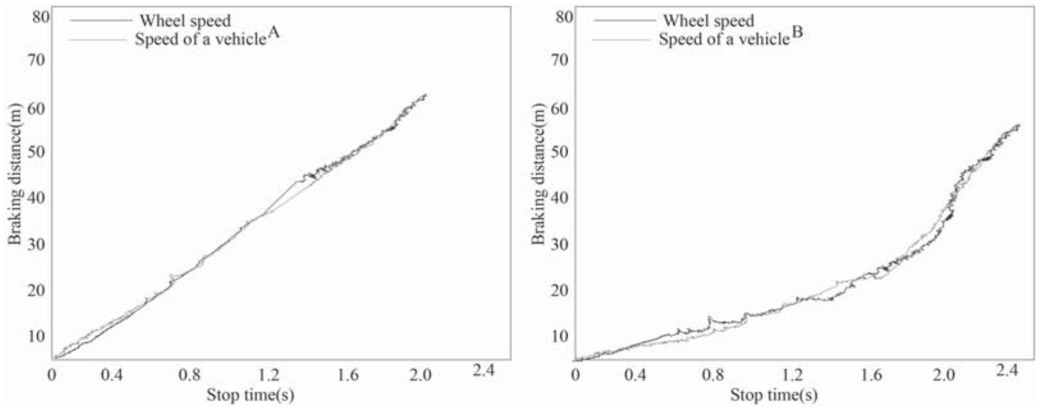

Figure 6 Comparison between braking distance and required stopping time of two vehicles.

3. EMPIRICAL EVALUATION ON PATTERN RECOGNITION OF AUTOMOBILE ABS

In order to determine the overall performance of the automobile ABS, in this paper, an empirical analysis was conducted through pattern recognition. This paper analyzed the initial speed when braking, the overall situation of the road surface and the pattern recognition results of the braking force on the automobile braking performance.

3.1 Evaluation Methods for Pattern Recognition of Automobile ABS

In order to conduct an empirical study of the automobile ABS, this paper compared the difference between the automobile with and without the ABS by pattern recognition, and relevant conclusions were drawn.

3.2 Pattern Recognition Results

3.2.1 Pattern Recognition Results of Initial Speed During Braking

For the pattern recognition of wheel speed and vehicle speed in initial speed during braking, this paper selected two types of vehicle speed and initial speed of wheel speed during braking for pattern recognition. The results are shown in Figure 5.

A: Initial wheel speed and vehicle speed with ABS
B: Initial wheel speed and vehicle speed without ABS

It can be seen from the pattern recognition of the initial wheel speed and vehicle speed of the two vehicles in Figure 5 (A) and Figure 5 (B) that when the distance between the two vehicles was the same, the time required for vehicles with ABS was shorter than that for vehicles without the system. When the distance was close to 80, the time required for vehicles with the system installed was 2 seconds, while that for vehicles without the system was 2.4 seconds. The time required for vehicles with the system installed was 0.4 seconds less than that for vehicles without the system. It can be seen that the performance of vehicles with ABS was better than that of vehicles without the anti-lock system.

In addition to the pattern recognition of the initial wheel speed and vehicle speed of the two vehicles, this paper also compared the braking distance and stopping braking time of the two vehicles. The specific results are shown in Figure 6.

A: Required stopping time of vehicle with ABS
B: Required stopping time of vehicle without ABS

It can be seen from the pattern recognition of the braking distance and the required stopping time of the two vehicles in Figure 6 (A) and Figure 6 (B) that the braking stopping time required for vehicles with ABS was less than that required for vehicles without ABS. This meant that in case of emergency

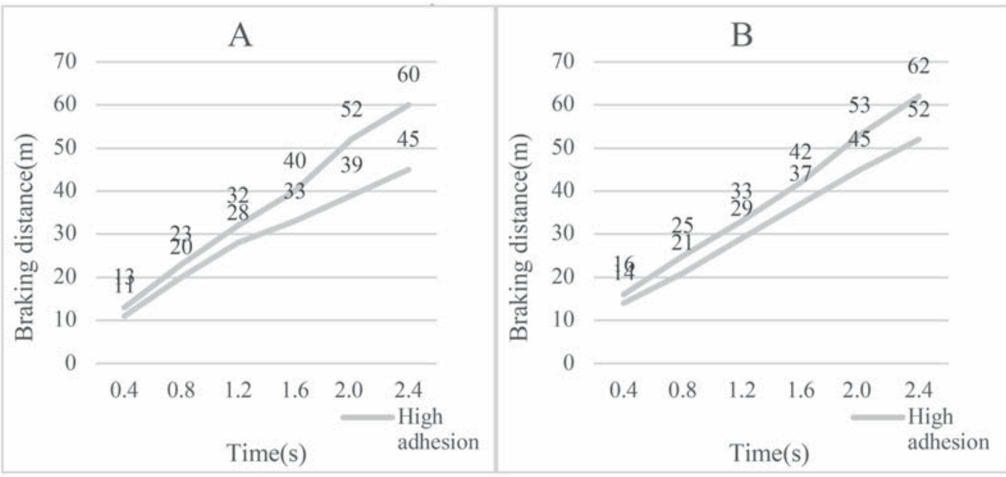

Figure 7 Pattern recognition results for braking distance and time.

Table 1 Braking force and braking distance identification results at 2.4 seconds.

Serial No	Braking force (N)	Braking distance (m)	
		Install	Not installed
1	200	48	57
2	400	41	52
3	800	37	48

braking, vehicles with ABS can brake faster and better respond to emergencies, which is vital for driving safety.

3.2.2 Pattern Recognition Results of Overall Pavement Conditions

As an important factor affecting the braking performance of vehicles, the pattern recognition of the overall road condition is of great significance. Generally, the overall condition of the road surface can be divided into high adhesion coefficient pavement and low adhesion coefficient pavement. The identification of braking process of road vehicles with two coefficients is shown in Figure 7.

A: Comparison of braking distance and time between two roads with ABS

B: Comparison of braking distance and time between two roads without ABS

It can be seen from the pattern recognition of Figure 7 (A) and Figure 7 (B) that the braking distance of vehicles equipped with ABS was shorter and the possibility of locking was lower in the same time, whether on the road with high adhesion coefficient or on the road with low adhesion coefficient. When the time was 2.4 seconds, the braking distance in Figure 7 (A) was 60 meters on the road with high adhesion coefficient and 45 meters on the road with low adhesion coefficient. In Figure 7 (B), the braking distance was 62m on the road with high adhesion coefficient and 52m on the road with low adhesion coefficient at the same time. The braking distance of vehicles equipped with ABS was 2 meters shorter than that of vehicles not installed on roads with high adhesion coefficient, and 7 meters shorter on roads with low adhesion coefficient. This showed that the performance of vehicles equipped with ABS would be better than that of vehicles without the system. At the same time, it can be seen that in the same time, the braking distance of vehicles on the road with high adhesion coefficient would be longer, which meant that the road conditions would also have a certain impact on driving safety.

3.2.3 Braking Force Identification Results

As the inertia force that can stop the automobile, braking force is very important for automobile braking. Generally speaking, the greater the braking force, the smaller the braking distance. The results of pattern recognition of braking force and braking distance when the braking time of the two vehicles was 2.4 seconds, are shown in Table 1.

It can be seen from Table 1 that when the braking force was 800N, the braking distance of the vehicle with the system installed was 37m, while the braking distance of the vehicle without the system installed was 48m. The braking distance of the vehicle with the system installed was 11m less than that of the vehicle without the system installed, which indicated that the braking performance of the vehicle with ABS is optimized. In addition, the pattern recognition of braking force and braking distance was also carried out for two kinds of vehicles when the braking time was 0.4 seconds. The results are shown in Table 2.

It can be seen from Table 2 that when the braking force was 800N, the braking distance of the vehicle with the installed system was 11m, while the braking distance of the vehicle without the installed system was 17m. The braking distance with ABS installed was 6 meters less than without ABS. By means of pattern recognition of braking distance and braking force in different time periods, it can be seen that the braking distance of vehicles equipped with ABS was shorter under the

Table 2 Braking force and braking distance identification results at 0.4 seconds.

Serial No	Braking force (N)	Braking distance (m)	
		Install	Not installed
1	200	15	20
2	400	13	18
3	800	11	17

same braking force, and the locking problem was less likely to occur, which is vital to the safety of vehicles during emergency braking.

To sum up, through the pattern recognition of the initial speed, the overall condition of the road surface, and the braking force when the vehicle brakes, it can be seen that the ABS was extremely practical for the vehicle. The braking distance of vehicles with ABS was 2 meters shorter than that of vehicles without ABS on roads with high adhesion coefficient, and 7 meters shorter than that of vehicles without ABS on roads with low adhesion coefficient. When the braking force was 800 N, the braking distance of vehicles with ABS was 11 meters less than that of vehicles without ABS. This showed that the ABS can reduce the braking distance of a vehicle and the occurrence of the anti-lock phenomenon, which enables the vehicle to cope with emergencies and improve driving safety.

4. CONCLUSION

With the development of data management systems, their application in daily life has become increasingly common. As a branch of data management systems, pattern recognition is often used to identify automobile systems. This paper first introduced the research background of the study, and then summarized and analyzed the previous scholars' research on automobile ABS. Combined with theoretical analysis, pattern recognition of automobile ABS was carried out. Through pattern recognition, the performance of automobile ABS and the feasibility and practicability of its application to automobiles were better verified, which has reference value for improving driving safety and promoting the use of automobile ABS.

REFERENCES

1. X.Z. Zhang, Y.N. Wang, X.F. Yuan, X.J. Shen, ZY. Lu. Adaptive dynamic surface control with disturbance observers for battery/supercapacitor-based hybrid energy sources in electric vehicles, IEEE Transactions on Transportation Electrification (2022), July 25. DOI: 10.1109/TTE.2022.3194034.
2. J. Xu, S.H. Park, X. Zhang, J. Hu. The improvement of road driving safety guided by visual inattentional blindness. IEEE Transactions on Intelligent Transportation Systems, 23(6) (2022), 4972–4981. doi: 10.1109/TITS.2020.3044927.
3. V.G. Dankan. Modelling and performance evaluation of anti-lock braking system. J. Eng. Sci. Technol 14.5 (2019), 3028–3045.
4. Z.S. Zhang. Novel PMSM control for anti-lock braking considering transmission properties of the electric vehicle. IEEE Transactions on Vehicular Technology 67.11 (2018), 10378–10386.
5. Y. Wiseman. Efficient Embedded Computing Component for Anti-Lock Braking System. International Journal of Control and Automation 11.12 (2018), 1–10.
6. K.M. Algadah, S.A. Alaboodi. Anti-lock braking system components modelling. International Journal of Innovative Technology and Exploring Engineering (IJITEE) 9.2 (2019), 3969–3975.
7. Z.C. Ouyang, J.W. Niu, M. Guizani. Improved vehicle steering pattern recognition by using selected sensor data. IEEE Transactions on Mobile Computing 17.6 (2017), 1383–1396.
8. N. Boonsim, S. Prakoonwit. Car make and model recognition under limited lighting conditions at night. Pattern Analysis and Applications 20.4 (2017), 1195–1207.
9. D.V. Gowda, A.C. Ramachandra. Slip ratio control of anti-lock braking system with bang-bang controller. International Journal of Computer Techniques 4.1 (2017), 97–104.
10. A. Benine-Neto, X. Moreau, P. Lanusse. Robust control for an electro-mechanical anti-lock braking system: the CRONE approach. IFAC-PapersOnLine 50.1 (2017), 12575–12581.
11. S. Liu, J. Wang, Z. Wang, B. Yu, W. Hu, Y. Liu, Y. Hu. Brief industry paper: The necessity of adaptive data fusion in infrastructure-augmented autonomous driving system. In 2022 IEEE 28th Real-Time and Embedded Technology and Applications Symposium (RTAS) (2022, May), (pp. 293–296). IEEE.
12. X. Lu. Master cylinder pressure reduction logic for cooperative work between electro-hydraulic brake system and anti-lock braking system based on speed servo system. Proceedings of the Institution of Mechanical Engineers, Part D: Journal of Automobile Engineering 234.13 (2020), 3042–3055.
13. I.M. Zulhilmi. Experimental study on the effect of emergency braking without anti-lock braking system to vehicle dynamics behaviour. International Journal of Automotive and Mechanical Engineering 17.2 (2020), 7832–7841.
14. A. Andrei. Design of regenerative anti-lock braking system controller for 4 in-wheel-motor drive electric vehicle with road surface estimation. International Journal of Automotive Technology 19.4 (2018), 727–742.
15. J.C. Wang, R. He, Y.B. Kim. Optimal anti-lock braking control with nonlinear variable voltage charging scheme for an electric vehicle. IEEE Transactions on Vehicular Technology 69.7 (2020), 7211–7222.
16. X.Z. Zhang, Y.N. Wang, X.F. Yuan, X.J. Shen, Z.G. Lu. Adaptive Dynamic Surface Control with Disturbance Observers for Battery/Supercapacitor-based Hybrid Energy Sources in Electric Vehicles, IEEE Transactions on Transportation Electrification (2022), July 25. DOI: 10.1109/TTE.2022.3194034.
17. J.C. Wang, R. He. Hydraulic anti-lock braking control strategy of a vehicle based on a modified optimal sliding mode control method. Proceedings of the Institution of Mechanical Engineers,

Part D: Journal of Automobile Engineering 233.12 (2019), 3185–3198.
18. B.K. Lavine. Pattern recognition-assisted infrared library searching of the paint data query database to enhance lead information from automotive paint trace evidence. Applied Spectroscopy 71.3 (2017), 480–495.
19. Q. Wang, C. Zhang. Research on defect detection technology of automobile hub casting based on pattern recognition. Casting technology 38.12 (2017), 2889–2891.

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